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Quantifying the impacts of sustainable city logistics measures in the Mexico City Metropolitan Area

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Abstract

This paper discusses the assessment of the potential impacts of a number of city logistics measures proposed for the Metropolitan Area of the Mexico City Valley: off-hour delivery programs; policies and agreements to increase cargo consolidation and decrease empty trips; and the implementation of preferential truck routes. The analyses consider the impacts on travel distances, travel times, accidents, emissions and health impacts. In doing so, the authors discuss the proposed measures, the assumptions used to estimate the impacts, and the information required. Different scenarios are evaluated for the various measures.

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Keywords: empty trips; off-hour deliveries; preferential truck routes; emissions; congestions; health impacts

1. Introduction

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 10 pt. Here follows further instructions for authors.

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The Mexican urban areas, especially the metropolis and megalopolis, are experiencing major mobility challenges because of the high motorization rates, increased levels of personal auto use, urban sprawl, and deficient transport services, among others. These factors are producing enormous pressure on the passenger and freight transport systems and the built infrastructure. It is of great importance to recognize that although bringing the much needed flows required for the consumption and manufacturing sectors that are vital for these urban economies, the freight transport system is also responsible for the generation of negative externalities. These include increased fuel consumption, congestion levels, emissions, and pollutants that impact health, thus reducing the economic welfare of the region by directly impacting the productivity and competitiveness of the private sector, and producing detriments to the quality of life. If unattended, the conditions are expected to deteriorate resulting from the continuous growth in demand experienced in these cities.

During the last 20 years, the CO_2 emissions produced by the transport sector have increased by 87% (INECC, 2011). Additionally, the sector is one of the main generators of black carbon particulate pollutants and the precursors of the tropospheric ozone, which are part of the short lived climate pollutants (SLCPs) largely impacting air quality and climate change. It is estimated that in 2010, the health impacts due to air pollution represented a cost to the country equal to 4% of its gross domestic product (GDP), and about 57% of all environmental costs (INEGI, 2011; World Health Organization, 2011). In the case of the freight transport, the large freight vehicles operating in Mexico City, representing only 1% of the fleet, were responsible for almost 40% and 45% of the emissions of PM10 and PM2.5, respectively. Medium freight vehicles, representing 3% of the fleet, generated 20% of the particulate matter (SMA-DF, 2010). To remediate the issue, the Mexican Natural Resources and Environmental Office (Secretaría de Medio Ambiente y Recursos Naturales - SEMARNAT), and the Transport and Communications Office (Secretaría de Comunicaciones y Transporte – SCT) under the United Nations Framework Convention on Climate Change (UNFCCC) are interested in developing a National Appropriate Mitigation Actions (NAMA) program for the urban freight sector in the country. The NAMAs are a new concept that considers financing opportunities under the UNFCCC to help developing countries mitigate climate change (UNFCCC, 2011). Although there are no specified guidelines to develop the NAMAs, many countries and organizations are investing efforts and resources on their development at the local level.

The main objective of this paper is to discuss the results of a project to develop a NAMA program for the urban freight system in the Metropolitan Area of the Mexico City Valley. Specifically the paper describes the different city logistics measures analyzed to be implemented in order to reduce the environmental impacts of the freight system, as well as other externalities (Clean Air Institute, 2012). Although a set of 12 groups of measures were initially proposed, the final assessment of impacts only considered three: voluntary off-hour freight operations; updated policies/ cooperation agreements to increase cargo utilization to reduce empty trips; and improved conditions to foster the use of ring roads/subtilized infrastructure and develop preferential routes. The potential impacts from these measures were analyzed in terms of congestion, emissions, safety and health impacts. The analyses are based on performance scenarios with different levels of impacts in terms of shifts and reductions of vehicle trips (in different time segments and pieces of infrastructure), variable travel speeds, increased number of stops per tour, reductions in empty trips, and reductions in travel distances. In total 19 scenarios were designed considering international experiences and assessments of the Mexican conditions. It is important to mention that publicly available data were used to conduct the analyses, thus the results are expected to only provide an indication of the potential impacts. Moreover, data limitations only allowed estimating the impacts on the freight system and not on the urban transportation system as a whole.

2. City logistics measures

The authors conducted a comprehensive review of international city logistics measures from the perspective of their applicability to the Mexican context. The reader is referred to the Clean Air Institute (2012) for more information. After a preliminary assessment that included twelve categories, six measures were selected for further review: 1) Reduced tolls to the freight transport agents that participate in the Clean Transport Program (Programa de Transporte Limpio) established by the SEMARNAT. A program based on the SmartWay Program (U.S. Environmental Protection Agency, 2013); 2) Time restrictions for the freight traffic flows in the area; 3) Integral policy to foster intermodal centers and urban consolidation centers; 4) Updated policies/ cooperation agreements to increase cargo utilization to reduce empty trips; 5) Foster the use of ring roads/non-used infrastructure or develop preferential routes; and 6) Introduction of logistics and distribution technologies/routing for small fleets. The authors organized focus groups and interviews with federal and local officials, trade and other transport associations, and the private sector to perform a qualitative assessment of these potential measures. The qualitative assessment considered the perceived costs and benefits from each measure, and the constraints for their implementation. Table 1 shows the key findings.

Table 1: Key findings from the interviews and focus groups

Preferential tolls	• Most of the answers indicate that businesses participate in the Clean Transport Program to be able to get the preferential tolls • The cost of the tolls is important when deciding the use of the road
Time restrictions	• Widespread concern about the increase cost to freight receivers • Carriers have no flexibility to adjust operations because delivery times are set by the receiver/customer. • There were mixed perceived benefits from this measure

Urban consolidation centers	• General concerns about:
	  o Additional times due to consolidation at the facilities
	  o Quality of service for the final distribution
	  o Confidentiality when consolidating shipments for others
	  o Additional costs

Reduce empty trips	• General consensus about the need to:
	  o Reduce empty trips
	  o Increase operational load factors
	• Some business have participated in programs to coordinate shipments and deliveries. They are willing to learn more about other possibilities

Use infrastructure / preferential routes	• There are no special regulations or predefined routes for freight deliveries o In other cities such as Toluca and Tijuana there are • There is widespread lack of adequate signaling or clear and reliable information about better routes for goods distribution • There are only a few roads with low use in the city

Logistics and distribution technologies / routing for small fleets	• This measure received positive attitudinal responses:
	  o Businesses indicated their willingness to pay for logistical support
	  o There is interest to use technology to improve operations
	• They expect a reduction in operational costs with the use of technology
	• Small companies expressed concern about their ability to absorb the cost
	• There is concern about the governmental role in providing the service

Based on the findings, the team redefined some of these measures. Moreover, the analyses indicated that the measure to foster the use of multimodal and urban consolidation centers would not be a viable option for the scope of the NAMA program. The mixed results from international experiences validated the decision (Holguín-Veras, Amaya et al., 2014; Holguín-Veras, Jaller et al., 2014). The authors designed a survey that was administered to the public and private sector. The survey had two main sections, the first section gathered experiences and opinions about each of the measures, including questions about how likely were the respondents to adopt each measure. The second section, gathered qualitative data about the perceived impacts of the measure in terms of reductions in: a) greenhouse emissions; b) local air pollutants; c) traffic congestion; d) noise; e) travel times; f) operational costs; and improvements in g) road safety; and h) facilities and drivers safety. The introduction of logistics and distribution technologies/routing for small fleets was identified as an important contributor to the program. Consequently, the redesign of the different measures included this component in each of the other measures. Preferential tolls for those participating in the Clean Transport Program showed mixed ranking, though since it was already implemented, it was dropped from the analyses. At the end, three of these measures were selected for the quantitative assessment of impacts. For the final refinement of measures: the time restriction was redefined as a voluntary off-hour freight operations considering the documented experiences and analyses from New York, Spain and other locations (Holguín-Veras, Sánchez-Díaz et al., 2014); the introduction of technologies, programs, and updated policies/ cooperation agreements to increase cargo utilization to reduce empty trips; and the improvement of conditions to foster the use of sub utilized infrastructure and development of preferential/truck routes was redefined as the implementation of preferential truck routes.

2.1. Voluntary off-hour deliveries

Freight deliveries are one of the main activities contributing to the high levels of traffic congestion in many of the urban areas in the Mexico. The freight deliveries coincide, in most cases, with passenger flows thus increasing traffic levels. In addition, loading and unloading activities block roads and curb sides. This measure seeks to move freight traffic to time periods with less traffic, or to the off-hours. This is proposed as a voluntary program with the introduction of incentives to participating agents, especially the receivers of cargo (Holguín Veras, Marquis et al., 2013; Jaller and Holguin-Veras, 2013; Holguín-Veras, Sánchez-Díaz et al., 2014). The receivers are, as indicated by the focus groups responses, the ones that determine the delivery times, thus the carriers have to comply. The types of incentives considered on international experiences include: financial, in-kind and others. And the origin of the incentives could be both from the public and the private sector, such as financial incentives, grants, tax breaks, or shipper and carrier discounts, among others. In-king and other incentives include public recognition programs, and economic and development support (Holguín-Veras, Ozbay et al., 2011; Holguín-Veras, Wang et al., 2015). The experience in New York indicates that this program could foster an optimal shift between 10% and 30% of the freight traffic to the off-hours.

It is expected that the implementation of this measure could bring about similar results as the ones experienced in other locations such as New York City. In essence, for the carrier companies, off-hour operations could reduce travel times, given that lower traffic flows could increase travel speeds (in some cases up to 70% increase) (Holguín-Veras, Ozbay et al., 2011). This decrease in travel times coupled with a reduction in service times (from a median of 1.8 hours in the daytime to 0.5 hours at night) and parking availability, can be used to increase the number of stops per tour, thus maximizing the load factors and the efficiency of the fleet or warranting the use of larger vehicles. For the receivers, benefits include the reliability of service in terms of the delivery times, which could translate into an optimization of staff time, and a reduction in safety stocks (Holguín Veras, Marquis et al., 2013; Jaller, Holguín-Veras et al., 2013). Overall, the program could reduce congestion levels, decreasing emissions, and increasing economic competitiveness.

However, despite the expected benefits, there are some challenges that need to be overcome for the successful implementation of the program. The survey identified, consistent with findings in other areas, that the main challenges are in terms of safety and security of the cargo and drivers during the off-hours, increased logistics costs for some of the agents (especially for the receivers of the cargo), the potential for union issues, and additional costs and challenges in terms of legislation and enforcement. In general, similar perceptions have been found in other countries. Safety and security is very important, though anecdotic evidence in Sao Paulo Brazil indicates that, for carriers, the savings and direct benefits of the program are higher than the extra costs incurred even when hiring third party security and patrol for the trucks doing off-hour deliveries. In terms of additional staff or facility costs incurred by receivers, a similar approach such as the unassisted off-hour delivery program developed for New York City could be designed for Mexico. This type of operational scheme could also mitigate possible problems with union workers.

For this measure, Table 2 briefly discusses the assumptions and type of information required to assess the expected direct impacts of the measure. It is important to note that the current analyses have limitations and are meant to provide a general indication of the potential impacts. Considering the lack of available information, behavioral studies and real simulation tools, a number of scenarios were developed to assess the impacts of this measure. These scenarios are based on the findings of international experiences.

Table 2: Assumptions to assess the direct impacts of the off-hour delivery measure

Benefit	Description	Required information
Decrease in travel times: transferring freight flows to off-hours, results in higher average speeds for during the day hours.	Comparison between travel times during the daytime and off-hours. This is done by estimating the total travel time of the different types of vehicles under a set of assumptions and considerations.	Traffic flows by time segment. Average load factors. Average speeds for different time segments and vehicle types. Average load factors. Average travel distances per vehicle. Average travel times per vehicle.
Decrease in travel distances	Reductions in travel and service times can help increase the number of stops per tours. This translates in a decrease in the number of tours, which decreases the number of trips.	Same as for travel times.
Road safety	Accident rates per travel distances can be used to estimate safety impacts.	Safety rates per severity type per traveled mile.

Scenario 1 considers a:

a) Shift of 5% of freight traffic to the off-hours (19:00-06:00)

b) Shift of 5% of freight traffic to the off-hours (19:00-06:00), and a 10% increase in daytime speeds

c) Shift of 5% of freight traffic to the off-hours (19:00-06:00), and a 20% increase in daytime speeds

Scenario 2 considers a:

a) Shift of 10% of freight traffic to the off-hours (19:00-06:00)

b) Shift of 10% of freight traffic to the off-hours (19:00-06:00), and a 10% increase in daytime speeds

c) Shift of 10% of freight traffic to the off-hours (19:00-06:00), and a 20% increase in daytime speeds

Scenario 3 considers an increase of 1% in the number of stops per tour that could be made by the freight vehicle, a 5% shift in off-hour deliveries, and a 10% increase in speeds.

Scenario 4 is an optimistic case where 25% of the freight traffic is switched to the off-hours, producing a 20% increase in daytime speeds, and an increase of 5% in the number of stops per tour.

2.2. Policies/cooperation agreements to increase cargo utilization and reduce empty trips

One of the main inefficiencies of the freight transportation systems are the empty trips. These are mainly generated after the vehicles deliver their last shipment and have to return empty to their warehouse or origin. Different international studies have identified the proportion of empty trips in urban areas to be between 15% and 40% (Holguín-Veras and Thorson, 2000). In Colombia, Guatemala, and Dominican Republic, empty trips represent about 30%. In Colombia the proportion of around 30% of empty have remained constant during the last years (González-Calderón, Sánchez-Díaz et al., 2011). The purpose of this measure is to reduce empty trips. This is expected to be achieved by an active program that seeks to increase the cooperation and coordination among different businesses that allows for a more balanced dynamic of offer and demand of freight services and flows. In addition, the improvement and adoption of technologies by Mexican companies to optimize their fleets and to determine dynamic routing schemes would allow incorporating pick-up and delivery operations. It is also important that the program and policies developed in the Country foster reverse logistics operations which could greatly reduce empty trips and increase the efficiency of the fleet. Other important components for this measure include: the development of frameworks and information systems that could help companies make informed decisions, the use of logistics support systems and third party logistics providers, and the development of cargo consolidation schemes, especially those originated by the receivers.

The successful design and implementation of the measure is expected to bring direct benefits to the participating businesses and the transportation system. Increasing load factors and consolidating cargo would translate into less empty trips, and businesses will be able to reduce overall travel times by increasing the number of stops per route (or, without loss of generality, reduce the number of freight deliveries per destination). The survey conducted identified a number of challenges for the implementation of this measure. Mainly, challenges could arise in terms of cooperation between shippers and carriers, regulations, and the requirement of investments in technology. Cooperation between freight agents is vital, however, given the highly competitive nature of the freight system in Mexico, this represents a great challenge. It is important to mention that there are some industries, especially the auto industry, that have been able to develop sectorial clusters, and this trend is expected to increase. In terms of regulation, there are some pieces of legislation that limit the ability of some private carriers to transport cargo for other businesses. Similarly to the previous measure, a number of assumptions are considered to assess the potential impacts of policies and cooperation agreements to increase cargo utilization and reduce empty trips (see Table 3). It is required to estimate the proportion of empty trips in the study area and with the reduction scenarios, estimate the impacts on total travel distances. The different scenarios consider a reduction in the proportion of empty trips or more specifically, a reduction of empty traveled distances. Considering that the empirical evidence indicates that empty trips have remained almost stable in Latin-American countries, only minor changes are expected by this measure.

Table 3: Assumption to assess the direct impacts of policies and cooperation agreements to increase cargo utilization and decrease empty trips

Benefit	Description	Required information
Decrease in total travel distances	Increasing load factors and reducing empty trips carriers will reduce the total travel distances.	Total travel distance per vehicle. Empty trips. Average speeds.
Decrease in total travel times	Total travel times are estimated using average travel speeds.	Average speeds in different time segments and vehicle type.
Road safety	Accident rates per travel distances can be used to estimate safety impacts.	Safety rates per severity type per traveled mile.
Scenario 1: a) A reduction of 1% of the empty trips considering a 20% base case of empty trips. In essence, instead of 20%, 19.8% of trips are empty. b) A reduction of 5% of the empty trips considering a 20% base case of empty trips. **Scenario 2**: considers a reduction of 1% in empty trips with an increase in 1% in the number of stops per tour. **Scenario 3:** was designed to show the potential of the measure if 25% of the empty trips would be reduced. This represents a 5% net decrease in empty trips.		

2.3. Implementation of preferential truck routes in selected infrastructure

In most Mexican cities, freight vehicles generate various traffic problems such as the use of more than one lane, obstruct traffic when turning, creating jams when using bridges or tunnels not designed for their capacity, and deteriorate infrastructure when traveling on roads not designed for freight vehicles. It is also common that trucks travel in residential areas trying to avoid congestion or to reduce travel distances. In many cases, this is due to lack or inadequate signaling and information, and geometric design considerations. A remediating measure consists on the development and implementation of adequate signaling and allocation of preferential truck routes (BESTUFS, 2007). However, this requires great planning efforts about the estimation of freight traffic demand on different roads and highways. The measure considers road improvements, defining preferential truck routes, acceleration and deceleration lanes and access ramps, and other improvements to reduce the conflicts between various road users.

The implementation, careful planning and design of preferential truck routes could translate into reduced travel times between the major freight production and attraction zones. Moreover, the design and geometric changes implemented would improve road safety conditions and traffic flow conditions. The principal deterrent factor for the implementation of this measure refers to the lack of infrastructure capacity to accommodate preferential and dedicated truck routes. In addition, when there is no capacity, large capital investments would be needed. It is important to note that implementing preferential truck routes could reduce the available capacity to other road users, thus it could bring non-intended consequences and a degradation of the level of service to those users. However, in the Mexico City area, there is a high variability in terms of the flow capacity relationship between different roads and pieces of infrastructure. Therefore, it is important to properly identify the potential locations for implementation. Table 4 shows the main assumptions and considerations for the assessment of the direct impacts of this measure.

Table 4: Assumptions to assess the direct impacts of the preferential truck routes measure

Benefit	Description	Required information
Decrease in total travel distances and travel times	Improvements in freight routs could generate improved travel speeds and the identification of reduced travel distances between major freight production and attraction zones.	Freight flows per time segments. Load factors. Average speeds. Average travel distances per tour per vehicle type.
Road safety	Accident rates per travel distances can be used to estimate safety impacts.	Safety rates per severity type per traveled mile.
Scenario 1: a) Considers a 1% reduction in travel distances over the selected road links		

	b) Considers a 5% reduction in travel distances over the selected road links
Scenario 2:	a) + 5% speed increase over the selected roadways
	b) + 10% speed increase over the selected roadways
Scenario 3:	a) 1% reduction in travel distances over the selected road links + 10% speed increase
	b) 5% reduction in travel distances over the selected road links + 20% speed increase
Scenario 4:	Optimistic scenario assuming a 10% reduction in travel distances over the selected road links + 20% speed increase

2.4. Other benefits

In addition to the direct benefits previously discussed, the paper also estimates impacts on health (mortality and morbidity); and emissions (CO_2; $PM_{2.5}$; PM_{10}; CO; NO_X; COV). In general, emissions were estimated using the following functions:

$$E_i = \sum_j A_j Fe_{ij} \tag{1}$$

Where E_i represents the emissions of contaminant type i, A_j refers to the total activity of all vehicles in category j and Fe_{ij} is the emission factor of contaminant i for vehicle category j. The different contaminants considered are: CO_2, $PM_{2.5}$, PM_{10}, CO, NO_X, and COV. The emission factors used are based on the last emissions inventory reported for the Mexico City in 2010 (SMA-DF, 2010). The inventory offers factors for different vehicle types, fleet ages, and fuel types. Considering that the information available for the analyses did not provide enough level of detail. Weighted average factors were estimated considering reported fleet compositions.

There are diverse methodologies to assess health impact (Environmental Protection Agency, 2004; Krzyzanowski, Kuna-Dibbert et al., 2005; World Health Organization, 2011). In general, these methodologies evaluate health impacts from changes in concentrations of emissions and relative risks. In this work, a methodology developed by the World Health Organization and frequently used by Mexican National Institute for Ecology and Climate Change (INECC, 2011). This methodology estimates impacts on both mortality and morbidity. The methodology is based on the following general equation:

$$IS_{ij} = \Delta C_j FER_{ij} NT_i \tag{2}$$

Where IS_{ij} is the number of impact cases of health factor i associated with the change in contaminant j; ΔC_j is the change in concentration of contaminant j from the implementation of the measure; FER_{ij} is the exposition-response function expressed as a relative risk increase to the health factor i for a change in contaminant j; N is the population exposed to contaminant j and that could be affected by health impact I; and T_i is the mortality or morbidity rate associated with health factor $_i$ for population $_N$. The exposition-response functions were obtained from the published literature (Pope III, Burnett et al., 2002; Stevens, Wilson et al., 2005; INECC, 2013).

Table 6 shows a summary of the different scenarios evaluated for the direct impacts as well as for emissions and health impacts.

Table 5: Emission factors for the Mexican freight fleet

Contaminant	Grams / Kilometer	Contaminant	Grams / Kilometer
CO_2	507	CO	39
$PM_{2.5}$	0.214	NO_X	4.03
PM_{10}	0.253	COV	3.60

Table 6: Summary of evaluation scenarios

		Scenarios	Coding	*
Off-hour		a) 5% shift	M2-E1a-5%	
	1	b) 5% shift + 10% speed	M2-E1b-5%-10%vel	
		c) 5% shift + 20% speed	M2-E1c-5%-20%vel	
	2	a) 10% shift	M2-E2a-10%	

		Scenarios	Coding	*
		b) 10% shift + 10% speed	M2-E2b-10%-10%vel	
		c) 10% shift + 20% speed	M2-E2c-10%-20%vel	
	3	5% shift + 10% speed + 1% increase stops per tour	M2-E3-5%-10%vel+1%	✓
	4	25% shift + 20% speed + 5% increase stops per tour	M2-E4-25%-20%vel+5%	✓
Empty trips	1	a) 1% decrease empty trip distances	M4-E1a-1%	✓
		b) 5% decrease empty trip distances	M4-E1b-5%	✓
	2	1% decrease empty trip distances + 1% increase stops per tour	M4-E2-1%+1%	✓
	3	25% decrease empty trip distances	M4-E3-25%	✓
Truck routes	1	a) 1% decrease travel distance	M5-E1a-1%dist	✓
		b) 5% decrease travel distance	M5-E1b-5%dist	✓
	2	a) +10% speed	M5-E2a-10%vel	
		b) + 20% speed	M5-E2b-20%vel	
	3	a) 1% decrease travel distance + 10% speed	M5-E3a-1%dist+10%vel	✓
		b) 5% decrease travel distance + 20% speed	M5-E3b-5%dist+20%vel	✓
	4	10% decrease travel distance + 20% speed	M5-E4-10%dist+20%vel	✓

*Scenarios for which environmental, health, and safety impacts were assessed because they assumed a change in travel distances.

3. The freight system in the metropolitan area of the Mexico City Valley

The previous section have discussed the different city logistics measures considered for the development of the NAMA for the Metropolitan Area of the Mexico City Valley, and the assumptions to assess their potential impacts. A vital component of the assessment is to be able to characterize the freight system in the study area and identify the information required to implement the methodology developed. To this effect, the team gathered the limited information available about the freight system for Mexico City (SCT, 1992; UNAM, 2006; SMA-DF, 2010; INECC, 2011; INEGI, 2014). The references provided information about the various economic agents involved, characteristics of the freight fleet, the road network, aggregate traffic flows by different time segments and freight routes, accidents, emissions, and important operational characteristics such as average travel speeds, tour lengths, average stops per tour, among others factors.

In general, freight transport is performed by different types of services that include the vehicles that: enter the area; originate in the area but have a destination outside the area; have an origin and destination within the State of Mexico; have and origin and destination within the Federal District; and those that offer Federal services. Moreover, the freight vehicle fleet could be categorized as: i) public, ii) mercantile public; and iii) private. According to (UNAM, 2006), in 2004 there were about 440,000 (large) registered freight vehicles with an average fleet age of 15 years. This fleet showed a growth rate between 2.61% and 3%. Using these rates, about 624,000 vehicles were estimated for 2014. In addition to the registered fleet, it is expected that about 25% more vehicles travel in the study area. Estimates for 2004 showed that about 80,861 vehicles corresponded to Federal public service, 25,675 to local public, 284,380 vehicles were owned by companies in the private mercantile service with less than 100 vehicles, 47,695 by companies between 100 and less than 500 vehicles, and 37,327 by large private mercantile companies with more than 500 vehicles. As expected, the largest number of vehicles are owned by smaller companies, which is a characteristic of the atomization of the freight sector. The major types of vehicles include rigid 2 axle, single trucks, and semitrailers. Local services are offered using a larger proportion of smaller vehicles than freight trips in the Federal District. Registries for 2004, showed that there were about 96,000 businesses that owned freight vehicles, with a reduced number of them representing a large share of the vehicles. For example, Pepsico, Bimbo and Femsa Coca-Cola owned approximately 5 % of all private mercantile trucks. This large concentration of vehicles in a small number of companies offers great improvement opportunities. However, it also represents a challenge for the other smaller companies.

In terms of the road network, the Metropolitan Area of the Mexico City Valley has a very complex network with access control roads or highways, primary and secondary roads, local streets, ring roads, and others. In total there are about 976 kms of roadways without including local streets. Although there are no specified freight networks, the freight traffic does utilize a reduced number of access and connecting roadways with higher frequencies. It is important to highlight the following roads: Anillo Periférico, Eje Central, Circuito Interior, Calzada de Tlalpan and Eje 6 Sur as the ones widely used by the freight vehicles. The research identified a number of traffic flow restrictions in some of the roads in the network in addition to other measures such as the vehicle certification program, the “Hoy No Circula” (No Travel Today) and the program for Atmospheric Environmental Contingencies. Freight operations are performed at different time segments depending on the type of service. The vast majority of the freight traffic is observed during daytime hours and greatly reduces after 5:00PM. Table 7 shows the percentage of the fleet observed during each the time segment.

In addition to the carrier companies, for a full depiction of the urban freight system it is important to understand the economic agents that attract the cargo and freight trips. In the study area, the main principal economic activities include Commerce (57%), Service (34%) and Manufacturing. In 2004 there were 466,267 registered businesses that employed about 2,461,067 individuals. Among the special establishments that could generate the largest amount of freight trips are the supermarkets, wholesalers, bodegas or small shops, shopping centers, specialized stores, department stores, public markets, and hospitals. All of these have different logistic patterns, with different types of requirements, and serviced by various segments of the freight sector using a diverse type of vehicles. Considering the types of services and the freight agents, Table 8 shows a summary of the main characteristics of the operations in the study area.

Table 7: Operations by time of day

Type of service	**6-11**	**11-17**	**17-23**	**23-6**
Federal public	80.36%	65.48%	27.98%	9.52%
Local public	76.74%	76.74%	32.56%	2.33%
Mercantile private (less than 100 vehicles)	87.15%	77.83%	33.25%	4.28%
Mercantile private (between 100 and 500)	96.30%	85.19%	9.63%	0.25%
Mercantile private (more than 500)	98.02%	87.41%	7.16%	0.25%

Source: Author estimations based on (UNAM, 2006)

Table 8: Characteristics of the freight system agents in Mexico City

Type of Service	**Size**	**Characteristics**
Mercantile Private	Less than 100 vehicles	70% are small vehicles (2 axles, less than 3.5 tons)
		25% have staging areas 80% have a fleet with less than 5 vehicles 68% have a fleet with less than 3 vehicles Service 4 or less locations per day Mainly transport food products and furniture
	More than 100 vehicles	Service about 22 locations per day (pick-up and delivery operations) About 75% have a garage to spend the night Mainly transport processed food products Second most transported products are hazardous materials
Federal Public		90% are large trucks and semitrailers Perform about 2 stops in average per day 25% have a staging area 57% have a place to stay at night 15% are only through traffic About 13% do local operations Mainly transport minerals, building materials, furniture, manufactured food products and vegetables
Local Public		Service about 2 locations per day

Source: Author estimations based on (UNAM, 2006)

4. EMPIRICAL RESULTS

The references identified about the freight sector in Metropolitan Area provided detailed information about the proportion of trips for each service type, location and frequency of service. Moreover, information about the average tour length and number of stops per tour for different service types and vehicle class were available. Using the data and empirical observations in other similar locations, the authors estimated average traveling speeds for different vehicle types, for peak hours and off-hours and for two distinct road segments: inside and outside of congested areas. Speeds range from about 4 km/hr to 14 km/hr in peak times and from 14 to 22km/hr in off-hours for the congested areas. Table 9 summarizes the estimated total yearly traveled kilometers for the freight fleet. These distances are traveled according to the estimates in Table 10 for the different time segments. Considering the average speeds and composition of the type of stops per tour, the authors estimated that the 8 billion kilometers traveled by the fleet, are done in approximately 730 million vehicle-hours. It is estimated that the total distance traveled in the five most used roads (Anillo periférico, Eje Central, Circuito Interior, Calzada de Tlalpan and Eje 6 Sur) that correspond to the 18% of the total main built infrastructure are approximately 371,579,145 kilometers traveled in about 25,045,734 vehicle hours. Considering a 20% average rate for empty trips, in 2014 there were an estimated 1,611,708,303 kilometers traveled empty, with the highest share done by vehicles in the mercantile private sector (with less than 100 vehicles).

Table 9: Characteristics of the freight operations

Type of service	Average stops per tour	Average tour length (kms)	Kms/ stop	N of vehicles	Total yearly traveled kilometers
Federal public	2.10	62.80	29.90	104,631	1,042,215,375
Local public	1.80	49.60	27.56	33,220	154,807,413
Mercantile private (< 100 vehicles)	3.80	70.60	18.58	375,022	5,607,436,695
Mercantile private (100-500 vehicles)	23.80	56.50	2.37	62,897	752,630,700
Mercantile private (>500 vehicles)	22.20	48.10	2.17	49,224	501,451,334
Total				624,995	8,058,541,517

* Assumes 250 days and estimates for weekly, biweekly and monthly distributions for 39.5 weeks per year

Table 10: Total kilometers traveled in different time segments

	Time segment				
Type of service	06-11:00	11-17:00	17-23:00	23-6:00	N.A.
Federal public	421,947,844	343,817,133	146,915,140	49,986,853	79,548,405
Local public	63,066,947	63,066,947	26,758,663	1,914,855	-
Mercantile private < 100	2,375,963,185	2,121,872,802	906,491,978	116,685,283	86,423,446
Mercantile priv. 100-500	377,766,790	334,184,350	37,776,679	980,703	1,922,178
Mercantile priv. >500	254,556,216	227,002,233	18,594,394	649,246	649,246
Sub-total	3,493,300,983	3,089,943,465	1,136,536,855	170,216,940	168,543,274
Total					8,058,541,517

According to the Mexican National Statistical and Geography Institute in the Federal District and the State of Mexico, in 2012 there were about 25,249 road accidents from which about 463 (1.82%) resulted in fatalities and 8,195 (32.46%) resulted in injuries. About 47,839 vehicles were involved in those accidents, and 3,506 (7.33%) were freight vehicles, thus in total 1,850 accidents involved a freight vehicle. This in turn results in an average rate of .23 accidents per 100 million kilometers traveled. For the estimation of the impacts and running the scenarios, further considerations were made. For instance, for scenarios where the number of stops increased, this is only done to the trips performed by service segments in the lower range of stops per tour. It is difficult for services that are already performing more than 20 stops per tour to increase this number. For the case of the off-hour delivery program, speeds are expected to benefit in the day hours, while the speeds in the off-hours remain the same for the assumed shift percentages. For the preferential routes measure, analyses are only performed assuming its implementation will only be in the five most used roadways and the benefits for those roadways.

In general, benefits in travel distances and times translate in lower congestion levels, road degradation, fuel consumption, and operational costs. Figure 1 and Figure 2 show the potential percent reduction that could be achieved by the different measures under the considered scenarios. As expected, those scenarios that consider more optimistic impacts resulted in larger benefits. Moreover, the results indicate the largest benefits could be attained by the implementation of the off-hour delivery program. In terms of percent reductions from the base case, the implementation of the preferential truck routes seem to be a good alternative. However, the data did not allow for the estimation of the system wide impacts. In terms of travel times, again, the off-hour delivery program offers between 10% and 20% reduction. For the empty trips measure, although it should be a system objective to increase load factors and decrease empty trips, the scenarios considered were conservative which was reflected in the benefits. For this measure the maximum reduction estimated a 4% benefit in total travel times.

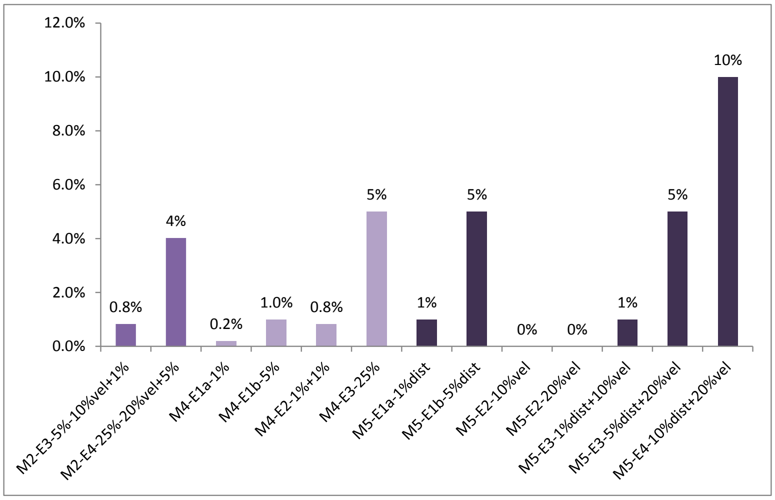


Figure 1: Percent reduction of total traveled distances

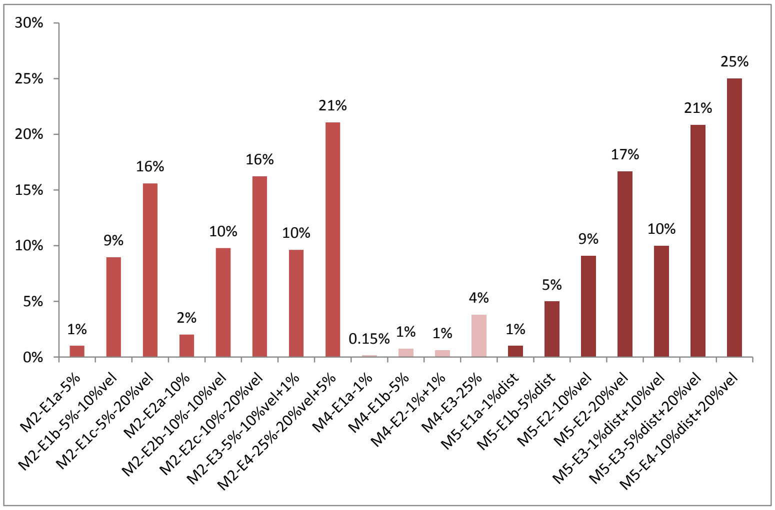


Figure 2: Percent reduction of total traveled times

Using the results obtained for the travel distances and travel times, the authors estimated total emissions for the base case. These resulted in yearly emissions of about 4 million tons of CO_2, 1,700 tons of $PM_{2.5}$, 2,000 tons of PM_{10}, 313,900 tons of CO, 32,500 tons of NOx, and 29,000 tons of COV. Figure 3 shows the estimated reduction in CO_2 emissions for the different scenarios. The figure shows that off-hour deliveries could reduce between 25,000 to

150,000 tons of CO_2 per year. Similar trends are observed in the results for reductions in $PM_{2.5}$. Figure 4 shows the average reductions in emissions for the different contaminant factors. The off-hour delivery program could produce overall emission reductions between .8% and 4%; the empty trips measure only shows significant improvements for the optimistic scenario that considers a 5% net decrease in empty trips; and while showing larger benefits between 1% and 10%, the reductions are only over the 5 main used roads for the preferential routes.

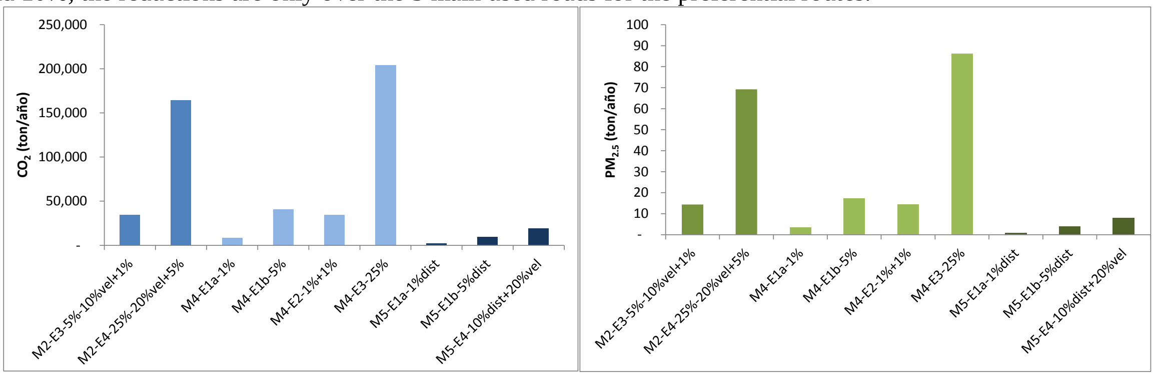


Figure 3: CO_2 emissions reductions (left) and $PM_{2.5}$ emissions reductions (right)

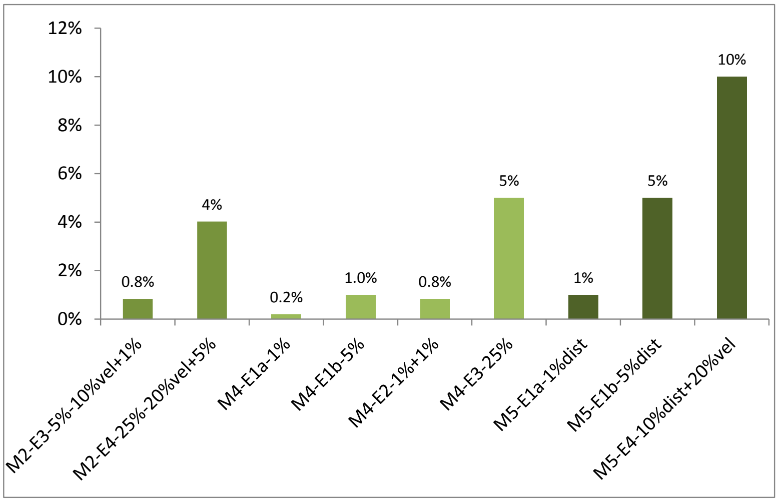
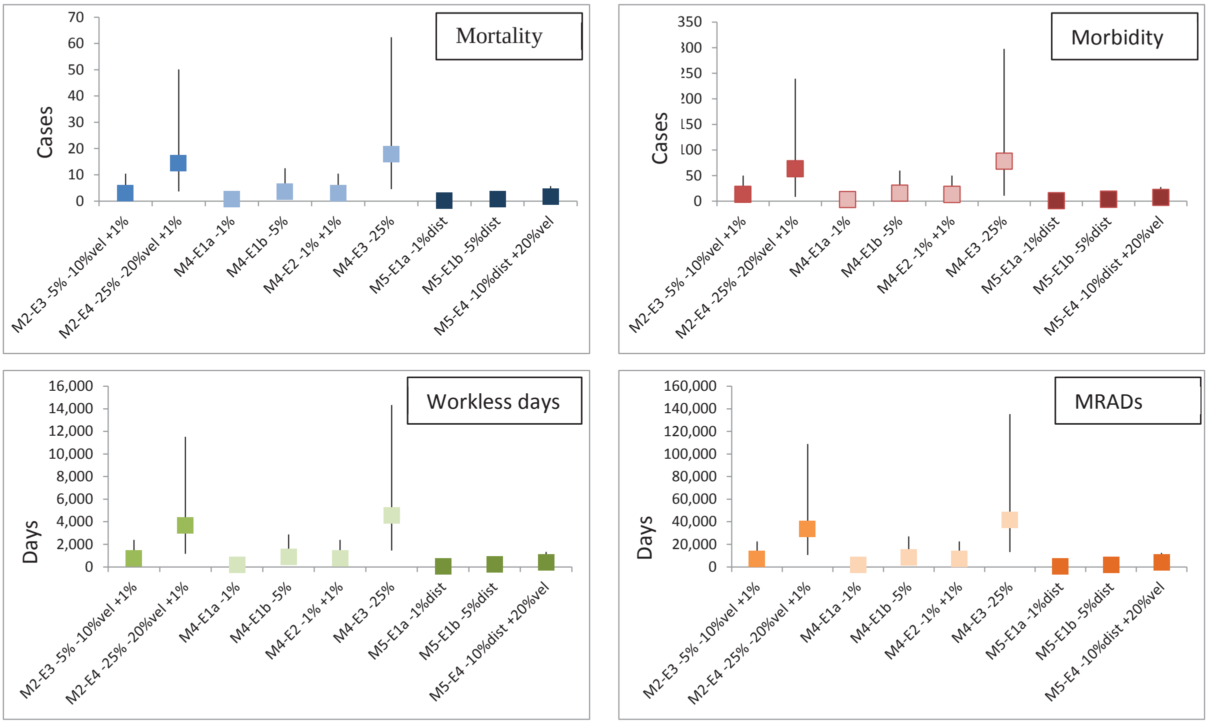


Figure 4: Average percent reductions for the aggregate of all emissions

Figure 5 shows the aggregate health impacts derived from the reductions in emissions for the different measures. The authors estimated health impacts in terms of mortality, morbidity, working days lost due to sickness and restricted work days (MRADs). The results are correlated with the findings for the reductions in emissions. It is interesting to see that even reductions of emissions of less than 1% bring about significant health benefits (decrease in mortality rates of more than 12 lives). For the optimistic scenarios lives saved could reach 110 per year by the emissions reductions. Although these are only illustrative estimations, they do show the potential health impacts of the considered measures. The different scenarios evaluated achieved modest benefits in terms of road safety. Off-hour deliveries could achieve reductions in accidents between .4% and 4%; reduction in empty trips (less total distance traveled) could reduce accidents between .2% and 5%; and preferential truck routes up to 10%.



*Minimum value: P=0.05; Median value: P=0.5; Maximum value: P=0.95

Figure 5: Health benefits derived from reductions in emissions

5. CONCLUSION

This paper discussed the results from qualitative and quantitative analyses to estimate the impacts of a number of city logistics measures proposed for the Metropolitan Area of the Mexico City Valley. The impacts considered reductions in travel distances, travel times, environmental impacts and their consequences on public health. The estimated base case for freight activity indicates that the freight fleet travels 8,058 million kilometers per year in 730 million vehicle hours, producing about 4 million tons of CO_2; 1,700 tons of PM2.5; 2,000 tons of PM10; 313 thousand tons of CO; 32,500 tons of NOX; and 29,000 tons of COV. The results obtained by the proposed measures are very promising. Considering the different scenarios, combined reductions in travel distance, emissions, and accidents could be in the order of 1% to 4% with the voluntary off-freight operations, 1% to 5% with the reduction of empty trips, and from 5% to 10% with the preferred and improved freight routes over the five most congested facilities. In terms of travel time, the results show benefits from 10% to 21%, 1% to 4%, and 21% to 25% for each of the measures, respectively. Although the percentage benefits may not seem significant, the emissions of CO_2 could be reduced by 150,000 tons per year by fostering off-hours operations. These results have great planning implications as they highlight the need for coordinated efforts between the public and private sectors. Investments in safety and security are needed to improve the overall conditions of the system which will foster the adoption of measures such as the off-hour delivery program. As identified in the focus groups and the survey, there is a need to develop information technologies that could help decision makers, not only in the freight sector but also in the passenger arena. Infrastructure improvements and the development of policies and regulations should be thought as a conduit towards a sustainable urban freight system in the Metropolitan Area, among others. However, the results presented do have some limitations that difficult the full assessment of impacts. As discussed, they are based on secondary data, thus there is a need to conduct more detailed analyses that involve data collection and modeling, which will allow considering the relationship between the freight system and the passenger system, and simulation tools that provide more accurate results. Despite these limitations, the type of analyses conducted could be replicated in other areas to quantify, in aggregate values, the impact of potential measures. Moreover, the findings from the interviews and surveys provide some indication of the attitudinal responses of the economic agents to these types of measures allowing for the transferability and comparability of international experiences.

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